Conceptual Design Description of the Gravity Reactor

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REVISION HISTORY

Rev	Date	Affected Section(s)	Description
0	See Approval page	All	This document was initially issued on 6/14/2024 as 2024-DF-LIC-001, “Conceptual Design Review of the Deep Borehole Pressurized Water Reactor (DB-PWR).” ADAMS accession number ML24172A286. This updated document is issued under new document ID, DF-LIC-WHP-001, and revised title, “Conceptual Design Description of the Gravity Reactor.”

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Acronyms

Acronym	Definition
ADAMS	Agencywide Documents Access and Management System
CFR	Code of Federal Regulations
DB-PWR	Deep Borehole Pressurized Water Reactor
DBA	Design basis accident
DBE	Design basis event
DiD	Defense-in-depth
DIH	Downhole instrumentation hub
DOE	U.S. Department of Energy
FR	U.S. Federal Register
GDC	General Design Criteria
IEEE	Institute of Electrical and Electronics Engineers
LEU	Low-enriched uranium
MWt	Megawatt thermal
NEI	Nuclear Energy Institute
NRC	U.S. Nuclear Regulatory Commission
NUREG	Nuclear Regulatory Report
PCC	Primary coolant control
PDC	Principal Design Criteria
PHX	Primary heat exchanger
ppm	Parts per million
PWR	Pressurized water reactor
RG	Regulatory Guide
RPP	Reactor Pilot Program
SHX	Secondary heat exchanger
SIH	Surface instrumentation hub
SSC	Structures, systems, and components
VIT	Vacuum-insulated tubing

1 Introduction and Purpose

This document provides an updated conceptual design description of the Deep Fission nuclear reactor design, the Gravity Reactor. It supersedes the 2024 conceptual design review white paper (Ref. 8.1.1).

The design described herein reflects continued engineering development, refinement of system configuration, and maturation of key design features. The information is provided to support technical understanding of the current design state and to facilitate regulatory and stakeholder engagement.

This document is not intended to establish licensing commitments, define the content of future regulatory submittals, or represent a final analysis of safety.

1.1 Background

In 2024, Deep Fission submitted 2024-DF-LIC-001, “Conceptual Design Review of the Deep Borehole Pressurized Water Reactor (DB-PWR),” (Ref. 8.1.1). The NRC provided written observations and comments in a meeting summary (Ref. 8.1.2). This white paper supersedes Reference 8.1.1 and applies Deep Fission’s recently established document control and numbering system. Whenever possible, based on design maturity at the time of submittal, Deep Fission integrated responses to NRC comments (Reference 8.1.2) in this document.

The Gravity Reactor is being developed within the U.S. Department of Energy (DOE) authorization framework for advanced reactor demonstration. Under this framework, DOE exercises authority over design, construction, and operation of the facility, including approval of the safety basis and authorization of startup.

The design and safety approach described in this document are being developed to support DOE authorization and to enable efficient transition to subsequent regulatory frameworks.

Detailed regulatory engagement activities, including planned interactions and submittals, are described separately in the Regulatory Engagement Plan.

1.2 Design Maturity

The Gravity Reactor design has progressed beyond the initial conceptual configuration described in the 2024 white paper (Ref. 8.1.1). The current design reflects:

- Refined system architecture and interfaces
- Updated reactor power and borehole configuration
- Improved definition of reactivity control strategies
- Integration of constructability and operability considerations

While the design has matured, it remains in a pre-final design phase. Certain design decisions, including the final classification of structures, systems, and components

(SSCs), continue to be evaluated through an iterative safety analysis and design integration process. The following significant updates have been incorporated:

- Reactor power and configuration updated to reflect current design objectives
- Borehole geometry revised
- Heat transport architecture modified, including relocation and reconfiguration of surface heat exchange systems
- Reactivity control approach expanded and under active development
- System groupings and terminology refined
- Removal of features no longer supported by constructability or operational considerations

These changes reflect the transition from an early conceptual design toward a more integrated and engineering-informed configuration.

2 General Plant Description

Deep Fission's Gravity Reactor is a compact pressurized water reactor (PWR) deployed in a deep, water-filled borehole. It uses inherent physical properties, rather than active systems or operator actions, to maintain reactor and public safety. There are several key safety features of the Gravity Reactor design that set it apart from conventional power reactors.

- **Separation from the surface biosphere**; dose rates are a factor of time, distance, and shielding, and the Gravity Reactor design separates its radiological source term nearly one mile from operators and the public.
- **Inherent pressure safety**; the mile-long hydrostatic column of water ensures that the pressure surrounding the reactor canister is nominally equal to the pressure within the canister, essentially eliminating the historical "Loss of Coolant" accident.
- **Large passive water supply**; the mile of borehole water precludes the need for offsite water sources for core cooling and scrubs and retains radionuclides within the mile-long water column in the unlikely event of a release.

In addition, Deep Fission has a design objective to maintain the safety of the reactor and the public with complete loss of surface facilities. This includes having no safety-related electrical power or operator actions and reducing reliance on traditional active reactivity control systems such as control rods. This objective is supported by preliminary analyses.

The design presented in this document reflects a defined system architecture and engineering approach. However, detailed design parameters, component specifications, and final safety classifications continue to evolve through ongoing engineering analysis, testing, and safety analysis.

2.1 Principal Site Characteristics

The plant consists of subsurface and surface systems.

- Subsurface: borehole casing, reactor canister, primary system, a portion of the secondary system
- Surface: control systems, borehole closure system (i.e., wellhead), secondary heat exchanger (SHX) and tertiary coolant system, power conversion, and support facilities

An overhead rig system similar to what is used in the commercial drilling industry raises and lowers the reactor to and from depth.

The Gravity Reactor fits in a roughly 38-inch inner diameter borehole with nominal 2-inch casing thickness at a depth of approximately one mile below ground. Figure 2-1 shows key plant systems and their relative positions. The 1-mile depth means the pressure inside the reactor (160 atm) is in equilibrium with ambient water pressure at that depth. The reactor produces 25 megawatts thermal (25 MWt), The reactor core and primary heat exchanger (PHX) are at depth.

The Gravity Reactor is surrounded by earth, which, combined with the mile-high column of water in the borehole, provides passive safety and geological isolation. The borehole water provides ample inventory for core cooling, and in combination with the earth along the length of the borehole, provides a sink for decay heat. These site characteristics and passive design features make fuel damage resulting from potential reactor transients extremely unlikely. In the unlikely event of an accidental release, deep geological isolation, which is further enhanced by the borehole water that acts as a scrubbing volume, minimizes the potential for radionuclide transport to the surface and dose consequences to the public and workers.

The Gravity Reactor is sited in locations where the depth of the reactor is well below the depth of water tables used for human consumption. Water tables used for human consumption are generally not deeper than 1000 feet, and the reactor is placed deeper than 5000 feet. Sites are also chosen where water tables at depth are hydraulically isolated and immobilized in the rock formation.

The modular design of the Gravity Reactor allows total power to be increased by adding more boreholes, each with its own reactor. Deep Fission’s fleet-wide licensing approach accommodates the installation of as many reactors as needed to meet customer demand.

A design objective of the Gravity Reactor is to have no safety-related electrical power so the plant remains safe through a loss of offsite and onsite power. Normal operation is synchronized to the electric grid, delivering power through a conventional generator and interconnection arrangement. The plant is compatible with current utility practices for synchronization and dispatch. The plant maintains stability under normal grid conditions and routine disturbances and responds to abnormal conditions and faults through coordinated control systems.

The electrical architecture supports coordinated operation and aggregation of output for multiple reactor units while maintaining clear unit-level isolation boundaries. This allows capacity to be scaled without requiring custom interconnection designs for each unit.

2.2 Fluid Flow Description

The Gravity Reactor is designed to operate up to full power using natural circulation as the means of providing reactor coolant flow, eliminating the need for reactor coolant pumps. Passive thermal-hydraulic behavior provides fission and decay heat removal during postulated events without operator intervention.

Under normal operating conditions, natural circulation drives the primary coolant system and pumps force flow in the secondary and tertiary coolant systems.

The primary coolant system consists of:

- Reactor canister and internals
- Nuclear reactor core

- Double-walled neck region connecting the reactor canister and PHX
- PHX, the shared heat exchanger between the primary and secondary coolant systems

The secondary coolant system consists of:

- The secondary side of the PHX at depth
- Secondary piping
- Pumps and valving
- SHX, the shared connection between the secondary and tertiary coolant systems

The tertiary coolant system consists of:

- Tertiary side of the SHX
- Turbine and electrical generator set
- Piping to take low temperature steam for other uses, such as industrial or combined heat and power, if applicable
- Condenser
- Pumps and valving

The borehole, which is cased in a steel and concrete structure and topped with the borehole closure device, is filled with water that is available for core cooling under all conditions. Figure 4-1 shows a cross section of the borehole. The figure shows the primary coolant control (PCC) tubes, which are used to obtain samples from the primary coolant system, inject and dilute boric acid and other chemicals, provide flow to filtration equipment, and to provide pressure control of the primary coolant system. The secondary pipe from the PHX to the surface is a double-walled, concentric, vacuum-insulated tube (VIT) with heated secondary water flowing up the central portion and cooled secondary water flowing down the annulus portion.

2.3 Principal Design Criteria

The Gravity Reactor requires that Principal Design Criteria (PDC) be identified. The Gravity Reactor PDC will be informed by the Title 10 of the Code of Federal Regulations (10 CFR) Part 50 (Ref. 8.2.1) General Design Criteria (GDC) framework and tailored to reflect the Gravity Reactor's unique design features and operating environment.

Design requirements are established and managed according to Deep Fission's engineering, quality, safety, and security programs using a graded approach.

2.4 Safety Considerations

Deep Fission's Gravity Reactor leverages geology, hydrostatics, and passive physics to eliminate key accident drivers and bound consequences.

This results in a safety case that is:

- Intrinsic rather than engineered
- Continuously passive rather than conditionally passive
- Physically isolated rather than administratively protected

Separation from surface biosphere: The Gravity Reactor is positioned approximately one mile below ground level in a cased borehole, establishing a passive separation between the reactor and the surface biosphere. This (1) provides orders-of-magnitude reduction in potential public dose pathways through distance and shielding; (2) converts traditionally dominant accident concerns (e.g., atmospheric release) into deep subsurface transport with long time constants; and (3) minimizes credible direct radiation exposure pathways to the public during both normal and abnormal conditions. Borehole deployment also provides inherent mitigation of external hazards such as aircraft impact and weather.

Inherent pressure safety: The Gravity Reactor operates within a water-filled borehole where the external hydrostatic pressure is roughly equal to internal system pressure, fundamentally altering the thermodynamic driving forces associated with loss of coolant accidents. This feature (1) prevents energetic primary coolant expulsion and (2) makes traditional large-break loss of coolant accident scenarios not physically credible in the conventional sense. This aligns with risk-informed, performance-based licensing approaches where initiators are physically eliminated rather than mitigated, reducing dependence on engineered safety system performance.

Large passive water supply: The surrounding borehole water column provides a continuously available heat sink and a natural scrubbing medium for radionuclides. Decay heat removal is accomplished through natural circulation and conduction to an effectively infinite heat sink, eliminating reliance on offsite water sources, active pumping systems, or operator responses. In accident scenarios, radionuclides are dissolved, diluted, and retained within the water column and subject to long transport times.

2.4.1 Seismic Safety

Because of the borehole design of the Gravity Reactor, Deep Fission considers several unique design features.

- Geology and siting: location-agnostic siting with borehole casing costs tailored to local geology.
- Depth underground: at a depth of one mile, surface motion fades and the bedrock moves as a single coherent block.

- Aquatic damping: borehole water resists fast motion and acts as a buffer around downhole components, constraining movement.

- Redundant groundwater protection: layered borehole casing uses the same technology proven in approximately four million existing boreholes in the United States.

- Demonstration and monitoring: sample well drilling and core extraction gives an unparalleled understanding of local geology, and updated data is obtained through sensors, inspections, and data reviews.

See Section 3.3 for planned seismic analyses.

2.4.2 Design Strategy

The Gravity Reactor's design reduces technical and execution risk by building upon proven technologies, established supply chains, and conventional industrial practices such as:

- Fuel and core technology: Using established low-enriched uranium (LEU) pressurized water reactor (PWR) fuel reduces qualification and procurement risk.

- Surface plant systems: The plant leverages conventional, well-understood power conversion and electrical equipment.

- Below ground operations: The plant uses established practices and engineered features from the deep borehole drilling and well industry, such as underground piping connections and borehole drilling methods.

- Industrial construction methods: Plant construction maximizes the use of modularization and offsite fabrication.

- Subsystem boundaries and interfaces: Clear interfaces between the subsurface nuclear heat supply systems, borehole systems, and surface facility support repeatability and reduce site-specific redesign.

- Program discipline: Requirements, quality controls, and verification activities are structured using a graded approach appropriate to material, risk, and credited functions, focusing engineering rigor and qualification effort where it most affects safety and performance.

2.4.3 Construction and Manufacturing

Major plant elements, especially those that benefit from controlled tolerances and rigorous quality controls, are produced in qualified fabrication environments and delivered to the site pre-assembled or as skidded systems. This may include factory-level assembly and verification of the reactor canister and internals, prefabrication of surface facility systems where practical, and standardized packaging for transport and handling. Factory testing is used to identify integration issues early.

2.4.4 Security

The facility security program integrates physical isolation, engineering barriers, security controls, and personnel reliability measures into a cohesive protection framework. By combining deep geologic inaccessibility with standardized security and cyber defense systems, Deep Fission achieves the equivalent of a hardened, actively guarded nuclear installation without a large protective force. After the installation of the reactor in the borehole, site security relies on the subsurface design and hardened borehole closure device for protection, potentially eliminating the need for continued on site armed guards.

Module control workstations connect to a separate, firewalled domain with tightly managed data transfer procedures. Network security protocols include intrusion detection, vulnerability management, access authorization, and incident response. These layered defenses ensure confidentiality, integrity, and availability of control systems and data associated with reactor operations.

Personnel receive specialized training in nuclear safety, cyber hygiene, and insider-threat awareness. Deep Fission employees performing safety- or security-critical tasks meet ongoing behavioral and medical suitability requirements as appropriate.

2.5 New and Used Fuel Management

The fuel handling and reactor core assembly system is in a surface facility. It loads the reactor canister with fresh, conventional, LEU fuel assemblies and conducts the initial assembly process. The assembly process is completed within the drilling rig structure including installation of nuclear instrumentation, filling of the canister with highly borated water to prevent criticality, and lowering the reactor into the borehole.

At the end of the planned operating cycle and after an appropriate cool-down period within the borehole, spent fuel is managed by either (1) storing the reactor canister in place within the borehole with the nominally mile deep column of water becoming its spent fuel pool, or (2) removing the reactor canister from the borehole and storing the spent fuel using conventional methods currently employed by operating PWRs.

The first approach precludes the need for handling activated fuel at the surface, resulting in substantial reduction of exposure risk to radiation workers and the public. It also reduces the need for spent fuel management infrastructure at the site surface.

Under the second approach, the used canister is retrieved as a unit and may be replaced with a fresh canister. The used fuel or the canister itself may be loaded into a dry cask for temporary storage onsite or for shipment elsewhere (e.g., to an interim storage facility, reprocessing facility, or long-term disposal site).

Both approaches can be implemented safely and in accordance with applicable requirements; increased security may be implemented for fuel movement operations as required by regulation. For either option, Deep Fission's modular approach facilitates operational continuity at multi-reactor sites. Refueling does not require taking the entire plant offline, thereby improving the capacity factor, energy availability, and grid stability.

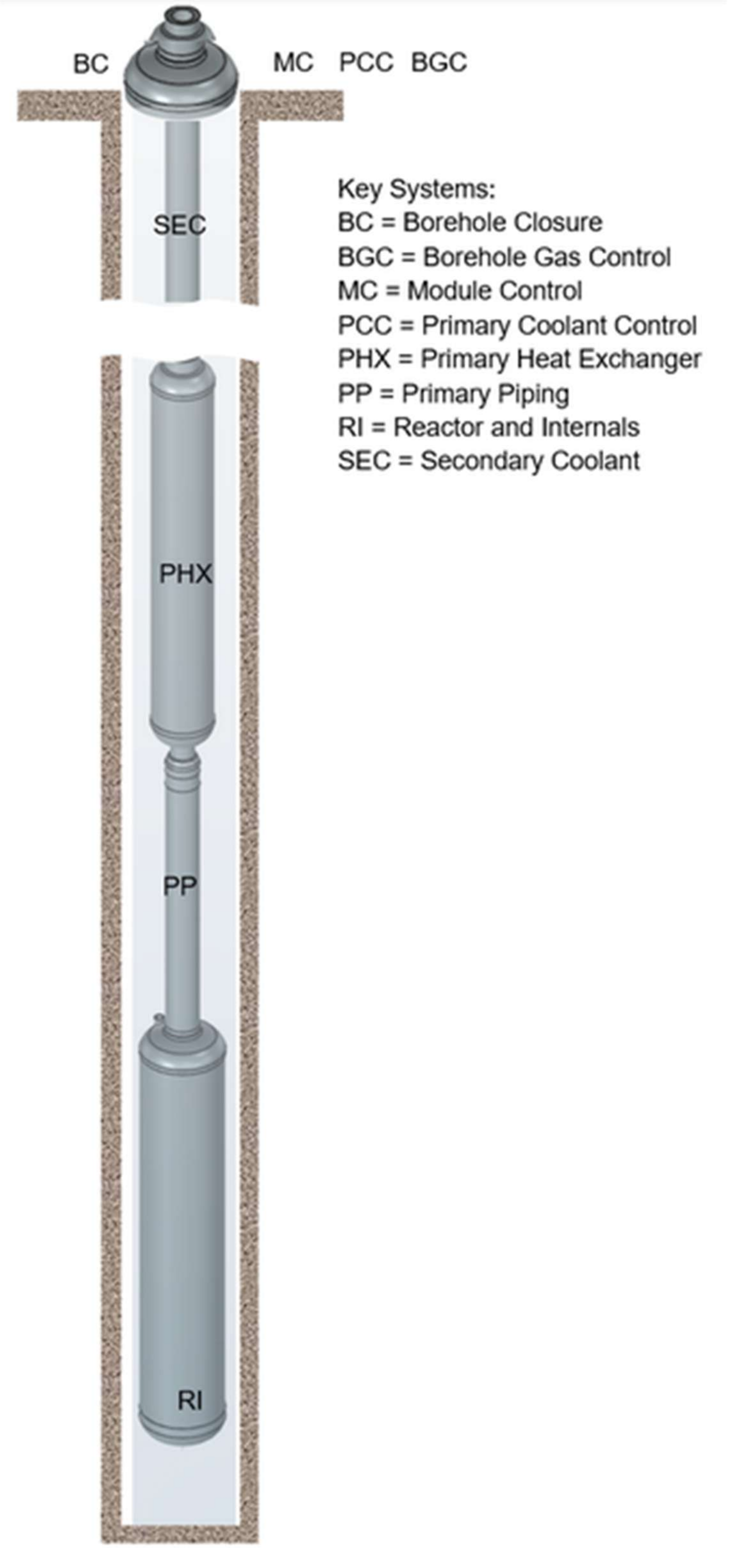

Figure 2-1: Key Plant Systems (not to scale)

3 Design Features, Engineered Safety Features, and Emergency Systems

The Gravity Reactor design applies a defense-in-depth approach that integrates inherent, passive, and engineered safety features to achieve the fundamental safety functions:

- Radioactive material confinement
- Nuclear reactivity control
- Fission and decay heat removal
- Preservation of adequate radiation shielding

The design leverages the unique characteristics of deep borehole deployment, including hydrostatic pressure, geological isolation, and reduced external hazard exposure, to support these safety functions. It also addresses several unique engineering challenges associated with deep borehole deployment:

- Long-distance heat transport between subsurface and surface systems
- Structural and material performance under high hydrostatic pressure
- Reliable signal transmission from downhole instrumentation
- Implementation of reactivity control mechanisms within constrained geometry
- Integration of drilling, installation, and nuclear system requirements

The design approach evaluates these challenges through analysis, testing, and iterative refinement. These considerations inform system configuration, material selection, and operational strategies.

3.1 Reactor Physics

The Gravity Reactor core implements conventional PWR design characteristics and benefits from the same negative reactivity feedback phenomena that result from increasing temperature. For example, Doppler broadening effects in the fuel and reduced coolant and moderator density both serve to limit core reactivity as its temperature increases. This is an inherent safety feature of the Gravity Reactor. In addition, the small size of the core supports stability in modes of normal operation because the higher neutron leakage creates a larger negative temperature coefficient of reactivity as compared to conventional PWRs.

3.2 Barriers to the Release of Radioactivity

The design incorporates multiple passive barriers, including:

1. Fuel matrix and cladding
2. Reactor canister
3. Borehole, including the water volume and borehole closure device, and surrounding geology

The primary barriers to the release of radioactivity in the Gravity Reactor are the fuel and its cladding, which are qualified to contain radionuclides under operating and transient conditions. The fuel is located within the primary coolant system, which consists of a reactor canister and primary coolant piping that creates an additional barrier. The coolant within the canister is passively maintained at an equilibrium pressure with the borehole water outside of the canister. This equilibrium pressure acts to minimize flow between the primary coolant system and borehole water in the event of a primary system breech, thereby slowing and limiting the release of radioactivity.

In the unlikely event that radionuclides are released from the fuel and its cladding, the massive one-mile deep column of borehole water above and around the reactor is the next barrier, as it effectively retains radionuclides and inhibits their transport to the surface. Geological isolation a mile underground further reduces the likelihood of transport and mitigates any potential release of radioactivity. Siting the Gravity Reactor one mile underground within a borehole makes transport through the borehole the only pathway for releases of radioactivity following postulated design basis accidents (DBAs). This design functionally ensures that radionuclides are confined. Additional defense-in-depth (DiD) is provided by a robust borehole closure device at ground level.

In the unlikely event of damage to the fuel and subsequent radionuclide release from the primary system, the vertical distance that dense, water-insoluble aerosols and heavier-than-air gases must travel against the force of gravity mitigates the transport of radionuclides to the surface. In addition, the scrubbing that occurs during the mile-long distance of travel through water mitigates the release of particulate radionuclides. Fission products that reach borehole water are deposited and dispersed in the large volume. Heat generation due to radioactive decay is transferred to the borehole water and then conducted through the casing into the surrounding earth.

The surrounding earth prevents rapid draining of the borehole. Borehole integrity is verified prior to installing the reactor.

3.3 Seismic Analysis

The design approach considers compatibility with risk-informed, performance-based regulatory frameworks for advanced reactors. Seismic analysis meets the intent of 10 CFR 100 (Ref. 8.2.3) Section 23, “Geologic and Seismic Siting Criteria,” and 10 CFR 50 (Ref. 8.2.1) Appendix S, “Earthquake Engineering Criteria for Nuclear Power Plants,” by following the guidance of NEI 25-08, “Graded Approach to Seismic Hazard Analysis and Corresponding Site Investigations for Licensing Nuclear Power Plants” (Ref. 8.3.2). The seismic hazard and site response is developed to meet the intent of NUREG-0800 section 4.2 appendix A (Ref. 8.3.3) and GDC 27.

Site-specific soil-structure interaction analysis of the casing and downhole assemblies is performed at the safe shutdown earthquake level based on subsurface material characterization. Those results are used to inform an understanding of potential for seismic-induced damage and informs the preservice baselines and post-event inspection triggers for the casing and downhole assemblies. This is anticipated to demonstrate that consequential seismic-induced casing damage is highly unlikely.

3.4 Emergency Core Cooling, Shutdown Decay Heat Removal, and Ultimate Heat Sink

The mile of borehole water ensures cooling is never lost. This eliminates the need for an active emergency core cooling or decay heat removal system. The water in the borehole serves as a passive core cooling mechanism that is always available when needed to cool the reactor via convection, natural circulation of borehole water, and conduction of heat to the surrounding earth.

During postulated events, decay heat is removed from the reactor through passive heat transfer. Because of the high pressure at depth, the water in the casing does not boil and transfers heat in same manner as during a normal shutdown. The amount of water in the casing is adequate to remove decay heat indefinitely.

3.5 Control Area Habitability

Control area habitability refers to providing adequate protection of operators against the effects of postulated releases of radioactivity or toxic gases. Damage to the fuel in the Gravity Reactor core that would make radionuclides available for release is made extremely unlikely by the inherent safety of the design. In addition, several design features, and engineered SSCs are available to mitigate potential releases from the core. Sources of chemicals that could present toxic gaseous hazards are minimized as appropriate and consistent with requirements. DBA analyses define the design features, SSCs, and actions necessary to maintain the habitability of the Gravity Reactor control area.

3.6 Radioactive Waste Management System

The radioactive waste management system is responsible for water removed from the primary coolant system through the PCC lines and other sources of radioactive waste in the plant.

3.7 Human Factors

The Gravity Reactor is controlled with minimal staffing and allows for possible remote operation in a centralized control area. Reactor controls are such that safe shutdown occurs regardless of human intervention. Digital systems in the control area relay required information to trained operators.

4 Major Systems

Beyond safety considerations, the design incorporates constructability and operability as primary drivers. The installation approach leverages established drilling and well completion practices adapted for nuclear system deployment. Key considerations include:

- Vertical installation of the reactor canister using proven handling methods
- Integration with surface borehole closure device and support structures
- Alignment and stability within the borehole

Operational considerations include:

- Remote monitoring and control from the surface
- Limited routine intervention in subsurface systems
- Defined approaches for retrieval, maintenance, or decommissioning activities

This section provides a description of the major plant systems in the current Gravity Reactor configuration, reflecting the present design state and engineering intent. Specific component selections, performance parameters, and final classifications continue to be refined as design development progresses.

4.1 Nuclear Heat Supply System

The Gravity Reactor heat supply system consists of a primary coolant system and a secondary coolant system that transfers heat without a phase transition. The secondary system transfers heat to and boils tertiary water to spin a turbine. The fluid used in all three loops is water. The reactor container is positioned beneath the PHX and is connected to it by a region of piping called the “neck,” as shown in Figure 4-3.

Natural circulation drives flow in the primary coolant system. Pumps drive flow in the secondary and tertiary coolant systems. As the reactor coolant flows through the PHX, heat is transferred to the secondary system water without physical contact between the fluids, heating the secondary coolant. Figure 4-3 shows primary and secondary coolant flow at depth. The surface-level SHX transfers heat from the secondary to tertiary coolant, producing high pressure steam for the turbine generator unit.

The design evaluates steady-state and transient behavior to ensure reliable heat removal across operating conditions. Key features and considerations include:

- Natural circulation driven by density gradients between the heated core region and cooler return paths
- Hydrostatic pressurization enabling high saturation temperature and stable boiling margins
- Long-distance heat transport via insulated conduits to minimize thermal losses between subsurface and surface systems

The design evaluates potential challenges such as flow stability, stratification, and phase behavior over the vertical extent of the system. Analytical models and testing are used to inform design margins and operational limits.

4.1.1 Reactor Core

The reactor core uses commercially available light water reactor fuel in a lattice configuration. The core design emphasizes:

- High heat transfer efficiency within a constrained geometry
- Compatibility with natural circulation cooling
- Manageable power density and flux distribution

The reactor's major components at depth are shown in Figure 4-3 and Figure 4-2. The reactor core contains four standard PWR fuel assemblies at lengths of either 12 or 14 feet. Each assembly has the standard 17 x 17 pin array with 264 fuel rods using LEU at less than 5% U-235 enrichment in uranium-oxide ceramic fuel. The light water coolant in and around the core provides neutron moderation, and the water outside the core acts as a reflector. The current design includes a reflector box to retain the capability to install a dedicated reflector. The reactor is contained in the cylindrical reactor canister.

Core neutronics, fuel performance, and burnup characteristics are under ongoing evaluation using established industry methods.

4.1.2 Reactivity Control

The Gravity Reactor incorporates multiple independent and diverse means of reactivity control to ensure safe operation and shutdown under normal and off-normal conditions. The configuration ensures reliability, controllability, and robustness within the geometric constraints of the downhole environment.

The current design emphasizes:

- Inherent feedbacks: Strong negative temperature and moderator density coefficients are leveraged to provide prompt and stable power response during transients. Additional negative reactivity feedback is provided by increases in fuel temperature (i.e., Doppler broadening). Core and coolant conditions are selected to enhance these feedback mechanisms while maintaining fuel performance margins. These passive feedback mechanisms deliver an autonomous and self-regulating response to transients.
- Supplemental reactivity management: Additional means of reactivity control are provided to meet regulatory requirements in the event the laws of physics fail. Chemical shim or alternative soluble or immobilized absorbers are evaluated to manage excess reactivity over the fuel cycle and to support shutdown margin where appropriate. This means of reactivity control is introduced by system(s) capable of introducing soluble boron or other absorbers into the core at various rates and concentrations. One of these systems is the PCC (Section 4.2.1), which provides active and adjustable reactivity management.

Key design considerations include:

- Minimizing reliance on moving parts within the primary system
- Maintaining controllability across startup, power maneuvering, transient, and shutdown conditions

This combination meets the intent of single-failure and independence criteria of IEEE-379-2014, “Standard for Application of Single-Failure Criterion to Nuclear Power Generating Station Safety Systems” (Ref. 8.3.1) and supports a DiD strategy. This reactivity control strategy leverages independent physical principles that do not share common cause vulnerabilities.

4.1.3 Primary Heat Exchanger (PHX)

The PHX is a shell and tube design adapted for operating in the borehole. It is at depth, above the reactor. Figure 4-3 shows the hot primary water first flowing to the top and then heating the secondary coolant system as it descends. No boiling is anticipated in the PHX.

4.1.4 Reactor Canister

The reactor canister is a cylindrical container that contains the reactor coolant, core, and associated internal components. The canister is designed to:

- Withstand external hydrostatic pressure.
- Maintain internal structural integrity under operational and transient conditions.
- Directs internal fluid flow.
- Contains the reactor coolant and nuclear fuel.
- Provide a barrier between the primary coolant and borehole water.

Material selection, wall thickness, and fabrication methods are being developed to meet these functional requirements.

Inside the reactor canister, internal components guide fluid flow, maintain core geometry, and support the structural loads of the fuel assembly components (Figure 4-4). The fuel assemblies are mounted and aligned to the lower core support plate by alignment pins located on the plate. The alignment pins constrain both axial and lateral movement and transfer mechanical loads to the canister shell. The fuel assemblies are aligned using mechanical interfacing alignment pins between the lower and upper core plates. Between the core support plates are an upper and lower fuel cell retainer that provide additional support for fuel assembly alignment; the upper retainer is spring loaded to transmit constant tension to the fuel and ensure a proper seat between the inlet and outlet surfaces of the fuel assembly.

The reflector box is between the fuel assemblies and the reactor canister, running from the bottom of the core to the inner connection of the neck region; the reflector box separates the outer downcomer and inner riser regions (i.e., the primary cold and hot leg, respectively). The reflector box does not contain a reflector in the current design; the box is there to allow a reflector to be added later in the design process if necessary. The neck region has a corresponding inner cylindrical portion containing heated primary water flowing upward surrounded by an annulus containing cooled primary water flowing downward. Approximately five former plates laterally secure the reflector box with respect to the reactor canister, adding to the lateral support provided by the lower core support plate. Former plates are perforated spacer plates attached to the reflector box between the upper and lower core support plates to maintain structural integrity and radial positioning.

Reactor internals are engineered to withstand seismic and operational loads while allowing for thermal expansion.

Structural members in the annulus between the reactor canister and borehole casing ensure enough clearance to allow for borehole water circulation while minimizing hydraulic losses.

The reactor vessel in a traditional PWR must safely contain 160 atmospheres of pressure difference, which is over 1 ton per square inch. A conventional pressure vessel has a thickness of several inches of steel, with great regard placed on the reactor vessel integrity over decades of life while it undergoes severe radiation exposure and frequent temperature and pressure cycling.

In contrast, the pressure differential across a Gravity Reactor canister wall is nearly zero when the borehole and primary system are filled with water. The pressure both inside and outside the primary system is set by the same height of water creating the same hydrostatic pressure, with minor differences associated with the ability to control primary pressure from the surface. The one mile depth was chosen because that height of water creates pressure conditions in the Gravity Reactor similar to those of conventional PWRs. This hydrostatic pressure is a key design feature achieved by placing the Gravity Reactor at depth.

For surface PWRs, the thick pressure vessel also serves as an additional barrier between the reactor core and the environment. For the Gravity Reactor this role is reduced; if the reactor canister is breeched, the path to the surface is a mile.

4.1.5 Primary Coolant System

The primary coolant system is expected to operate between 256 and 320°C, similar to the range used in gigawatt-scale nuclear reactors. Flow in the primary coolant system is driven by natural convection for normal operations.

The primary reactor coolant flow path is upward through the central hot leg riser, through the PHX, with return flow to the bottom of the core via a downcomer region in the annulus surrounding the core (Figure 4-3).

4.1.6 Secondary Coolant System

The flow in the secondary coolant system is controlled by surface-level pumps. The secondary coolant system remains liquid under normal conditions. The secondary piping between the PHX and the borehole closure device is a concentric, double-walled VIT where the hotter water flows up through the inner pipe, and the cooler water flows down the annulus on the outside of the inner pipe (Figure 4-1).

The mile-long pipe between the PHX and the borehole closure device is part of the secondary coolant system. The Gravity Reactor uses materials and processes from the deep borehole drilling and well industry to ensure the necessary stability and strength of the pipe for underground operating conditions.

4.1.7 Tertiary Coolant System

The secondary coolant system heated water flows through a SHX to transfer heat to and boil tertiary coolant system water. The steam is fed to a turbine generator to produce electricity, then cooled and conditioned to return to the SHX.

4.2 Primary Coolant Control (PCC)

The PCC system includes the set of systems and components that manage primary coolant conditions, including pressure, inventory, chemistry, and thermal response.

The PCC integrates both passive and active features, as appropriate to the function being performed. The PCC system allows incremental pressure control, sampling, and chemistry control of the primary coolant system water. It also serves as a pathway for water from the initial expansion of the primary coolant system when it is first heated to enter PCC tanks. Although the water in the primary coolant system is quite hot, the water in the PCC system is cooled by the casing water, which is, in turn, cooled by the surrounding earth.

4.2.1 Chemistry and Boron Control

Primary coolant chemistry is controlled to:

- Adjust reactivity
- Maintain material compatibility
- Limit corrosion and deposition
- Support fuel performance

The approach leverages established PWR chemistry practices, adapted for the sealed and remote nature of the system.

PCC operations are conducted on the surface. Purification is maintained by routing primary coolant through filter(s), resin(s), or demineralizer(s) at the surface as necessary to remove ionic contaminants such as chlorides and sulfates, capture particulates and corrosion products before they redeposit, and minimize activated products (e.g., Co-58, Co-60).

The Gravity Reactor maintains coolant chemistry within narrow bands for various chemicals during normal and off-normal operations, including reactivity control via boron concentration. The PCC ensures this balance by:

- Adding or removing boric acid solution through dedicated injection and dilution subsystems.
- Maintaining alkalinity to suppress corrosion while minimizing activation.
- Injection and dissolution of hydrogen gas into the primary coolant system.
- Supporting optional additives, such as zinc acetate.

Boric acid can be added to the primary coolant and the primary system's boric acid concentration can be diluted through the PCC system. Boron concentration control requires storage of water in PCC tanks adjacent to the borehole.

Particulates removed by the PCC filtration system potentially produce radioactive filters which require storage and eventual disposal off-site. The volume of these filters is small.

4.2.2 Pressure and Inventory Control

Primary system pressure is primarily established by the hydrostatic head of the borehole water column. The design evaluates supplemental features to:

- Maintain desired pressure margins
- Accommodate thermal expansion and contraction
- Manage transient conditions

The pressure control system consists of a small diameter vent line that rises from a high point in the primary coolant system to the surface. Connecting the vent line to a high point allows gases generated in the primary system to be removed as necessary. This tube provides pressure via the hydrostatic height of the tubes, one atmosphere of pressure for every 10 meters of depth. The pressure at the surface is close to atmospheric pressure, although it can be incrementally adjusted at the PCC tanks. The pressure in the primary coolant system is the hydrostatic depth of the water (approximately 160 atm) plus the positive or negative pressure of the surface tank. Figure 4-3 and Figure 4-1 show the PCC tubes in relation to other systems

4.3 Borehole

The borehole environment itself is not a plant system. It is the unique location wherein the Gravity Reactor is sited and is integral to plant performance. The design considers the coupled behavior of the reactor system and the surrounding geology. Key aspects include:

- Hydrostatic pressure established by the water column is nominally equal to primary system pressure
- Thermal coupling to geology, providing a distributed heat sink that contributes to long-term heat rejection

- Radionuclide transport pathways, which are limited by engineered and natural barriers

The borehole consists of:

- Steel casing and liner systems
- Cemented annular regions
- Interfaces with the borehole closure device

The borehole supports installation, alignment, and long-term stability of the reactor canister.

The borehole is composed of a roughly 38-inch diameter hole drilled nominally 1-mile deep that is filled with water and contains equipment associated with the primary and secondary coolant systems, instrumentation and control equipment, and the PCC tubing. The borehole is lined with a cylindrical metal casing that adds strength and uniformity to the inner walls of the borehole and prevents loose rocks from falling into the borehole.

After installation of the metal cylindrical borehole casing, concrete is forced up from the bottom of the hole around the metal portion and surrounds the bottom and sides of the hole. In addition, the borehole closure device, which is discussed in Section 4.3.1, is added at the surface. Figure 4-1 shows a conceptual profile of the borehole above the PHX. The borehole follows federal and local guidelines for deep borehole and well drilling. The design basis of the Gravity Reactor does not credit the borehole casing system for radioactive material confinement; however, it is a robust structure that provides DiD.

The borehole casing and closure device are intended to remain in service across multiple reactor operating intervals. The specific lifetime depends on site geology, final design, corrosion management effectiveness, and inspection and monitoring data gathered over time.

The borehole can be monitored and maintained using proven techniques from the deep borehole and well industry. These might include visual inspections of the casing for signs of corrosion using a remote camera, borehole pressurization to verify casing integrity, or sampling of the water within the casing.

4.3.1 Borehole Closure System

Figure 4-5 shows a potential design for the borehole closure device (i.e., wellhead). The device (1) provides liquid and gaseous confinement and (2) supports the weight of the PHX, reactor and reactor canister, and underground piping and instrumentation. The design is similar to a typical borehole wellhead from the deep borehole and well industry.

During construction, the closure device is welded to the borehole casing at ground level. The VIT running above the PHX is attached to the borehole closure device via a threaded connection. The threaded connection is a highly specialized, premium, engineered connection type used in the deep borehole drilling and well industry.

4.3.2 Hydrostatic Environment

The borehole is filled with water, creating a hydrostatic environment that:

- Equalizes pressure across the primary-to-casing and secondary-to-casing boundaries
- Contributes to heat rejection, keeping the casing cool
- Acts as an additional barrier to radionuclide transport
- Provides scrubbing of potential releases of particulate radionuclides resulting from unlikely fuel damage

The borehole water – in combination with the surrounding earth – acts as the ultimate heat sink and provides emergency core cooling and normal shutdown decay heat removal. During shutdown or a DBA, decay heat is removed from the primary utilizing passive heat transfer. Heat conducts and convects from the core to the walls of the reactor, through those walls, and to the water between the reactor canister and the borehole casing. Borehole water naturally convects heat away from the reactor canister. The borehole water convects upward, carrying away heat, depositing most of it in the borehole casing and surrounding earth along the way and is replaced by higher density cool water flowing downward. Because of the high pressure at depth the borehole water does not boil. The amount of water in the borehole is adequate to remove waste heat indefinitely.

4.3.3 Thermal Interaction with Surroundings

The design considers heat transfer from the borehole to surrounding geological formations. This interaction contributes to long-term heat rejection and influences transient response.

Thermal performance is evaluated using analytical models and, where applicable, testing.

4.4 Fuel Handling and Storage Systems

Fuel handling and storage systems support receipt, installation, removal, and storage of nuclear fuel. The design approach emphasizes:

- Minimization of handling complexity
- Use of proven handling methods where applicable
- Compatibility with the vertical borehole configuration

Section 2.5 describes used fuel storage methods under consideration.

4.5 Instrumentation, Controls, and Electrical Systems

Instrumentation and control systems monitor plant conditions and support safe operation. The design includes:

- Downhole instrumentation for process parameters such as flow, temperature, pressure, and neutron flux
- Signal transmission systems from subsurface to surface
- Surface control systems for monitoring and operation

The design addresses challenges associated with the downhole environment, including signal transmission over long distances, environmental conditions (temperature, pressure, radiation), and reliability of electronics and software systems.

Downhole sensors interface with electronics which are housed in a liquid-tight, pressure-rated enclosure called the downhole instrumentation hub (DIH) located deep within the borehole and above the reactor. The DIH communicates with a corresponding surface instrumentation hub (SIH). The SIH provides power to the DIH via submersible electrical cables. Sensor data is exchanged between the SIH and the DIH. The SIH communicates with the reactor-specific module control system, which then interfaces with the site-wide plant control system.

Signals associated with sensed conditions are generated from typical nuclear instrumentation (e.g., neutron flux detectors, resistance temperature devices, strain gauges) which are qualified to operate in their normal and abnormal environments.

The Gravity Reactor allows sampling of the primary coolant via the sampling tubes shown in Figure 4-1 and Figure 4-3. Boron concentration at the inlet and outlet of the PCC system on the surface is monitored by instruments which communicate with the module control system. Boron addition or dilution is controlled by boron injection system controls and distributed control system operations.

During normal operations, the electrical power distribution system provides continuous power to equipment needed for the plant's startup, operation, and shutdown.

4.6 Power Conversion System

The power conversion system transfers heat from the reactor to the surface and converts thermal energy into electricity. To the extent possible, the design consists of commercial off-the-shelf components. It includes a main steam system, a conventional steam turbine generator set, a conventional condenser and waste heat rejection setup, and a condensate and feedwater system (Section 2.2). Thermal energy is converted to electricity using conventional power generation equipment adapted to the system configuration. The design evaluates configurations that minimize thermal losses over long transport distances, maintain operational flexibility, and support efficient energy conversion.

Deep Fission anticipates these systems are nonsafety-related and not important to safety.

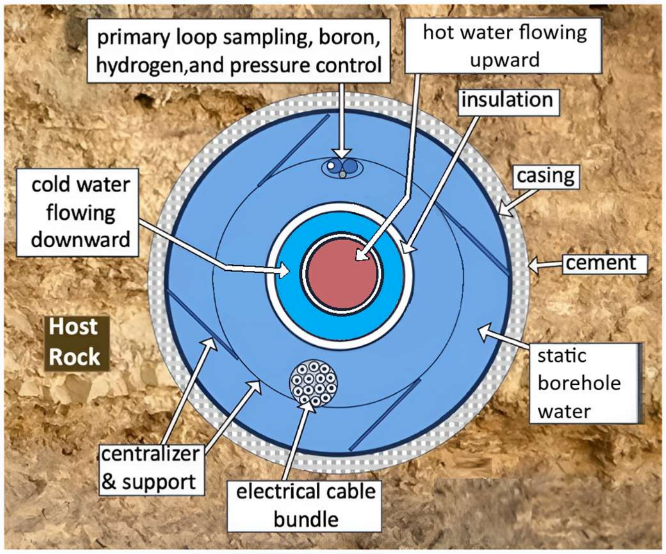

Figure 4-1: Conceptual Cross Section of Borehole above PHX (not to scale)

Figure 4-1 shows a cross section of the borehole above the PHX, from the PHX to the surface. The secondary coolant system has cold water flowing downward and hot water flowing upward in concentric VIT. The PCC tubes extend down to the primary coolant system. These tubes allow sampling and filtration of the primary water and serve as a means for boron, volume, and pressure control for the primary coolant system.

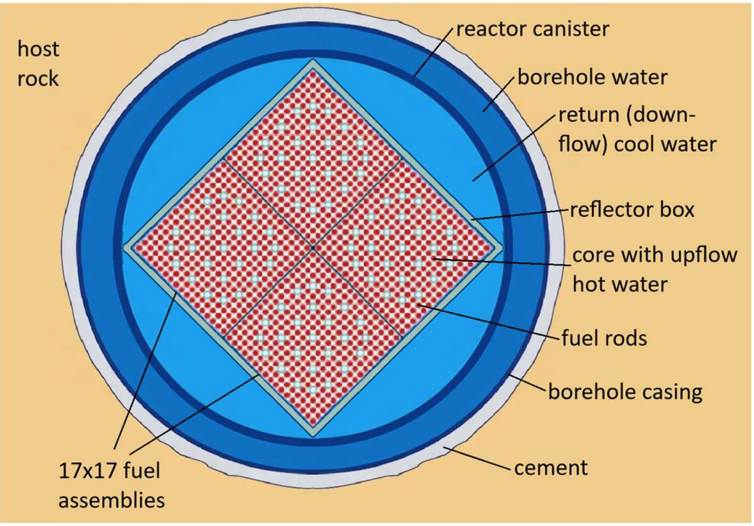

Figure 4-2: Plan View of Core (not to scale)

Figure 4-2 shows a cross section of the reactor core. The core consists of four conventional 17x17 fuel assemblies surrounded by a round reactor canister. The space between the fuel assemblies and the canister is the downcomer for return water from the PHX to reach the bottom of the core. The space between the reactor canister and the casing is occupied by borehole water.

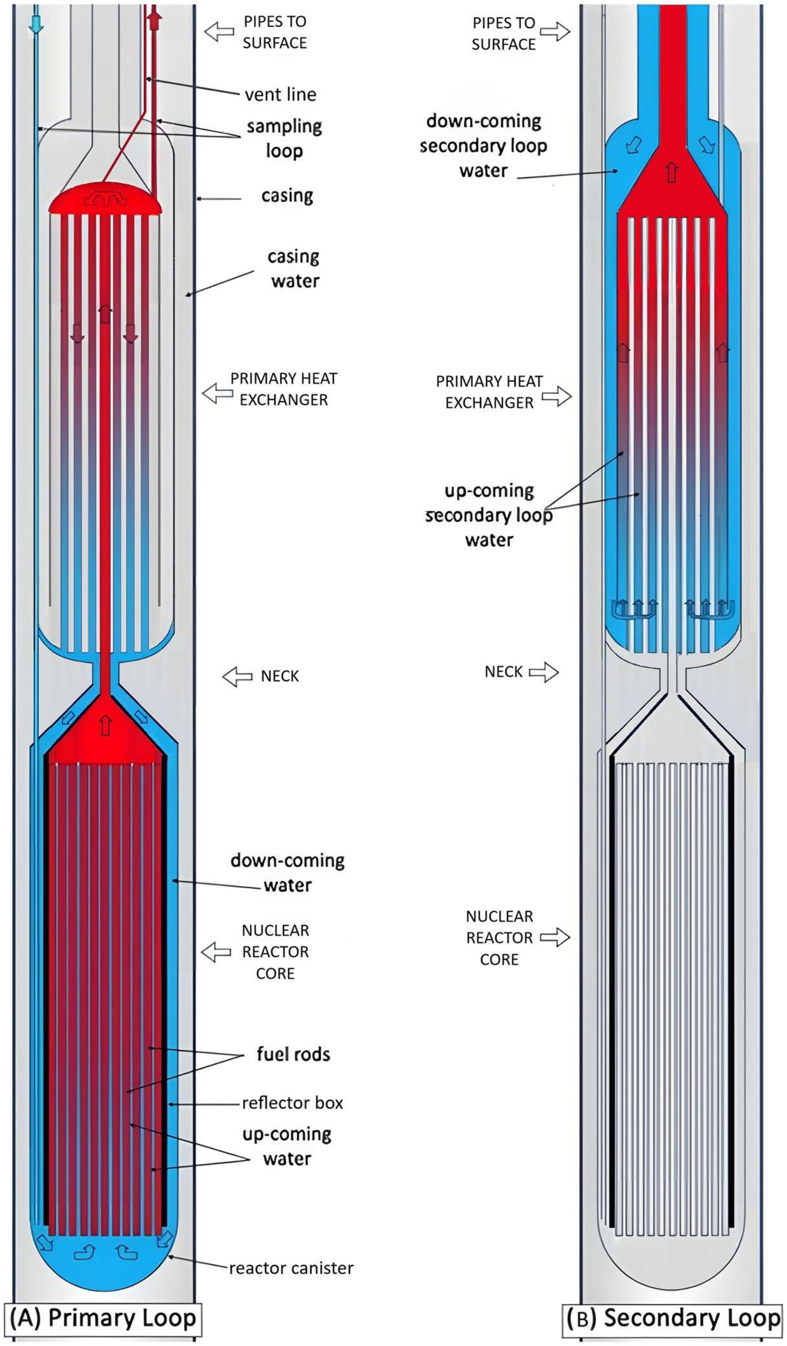

Figure 4-3: Primary and Secondary Fluid Flow Paths at Depth

Figure 4-3 shows major reactor components and primary and secondary flow at depth; this figure is only to demonstrate flow paths, and the diagram is conceptual and not to scale. Comparatively hot water for that flow path is shown in red and cold in blue. (A) shows the primary coolant system. Included is a proposed linear heat exchanger, although other designs are also under consideration. (B) shows the secondary flow through the PHX.

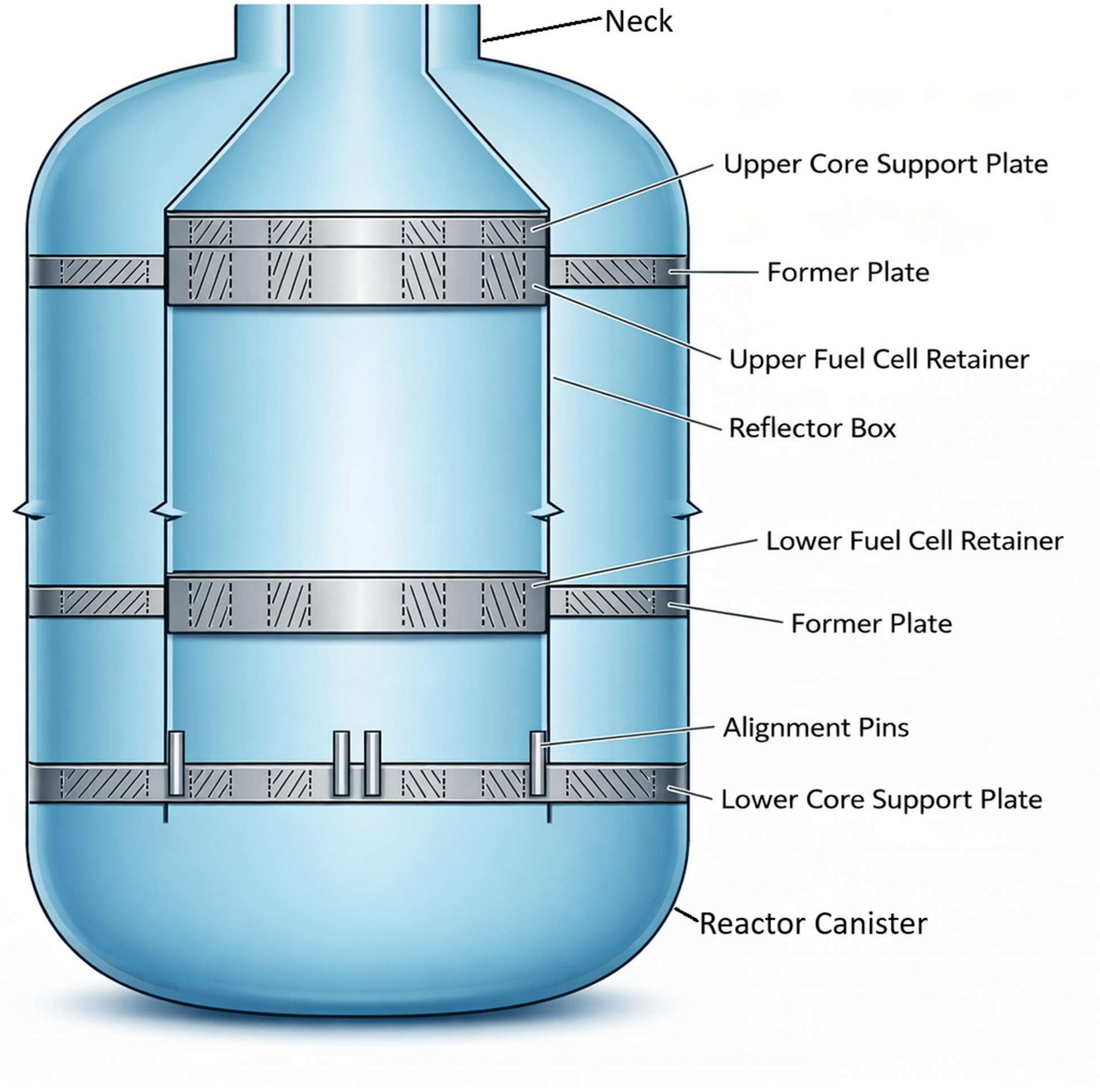

Figure 4-4: Reactor Internal Support Placement in the Reactor Canister

Figure 4-4 is an illustration (not to scale) of the reactor internal support placement within the reactor canister. Hashed lines represent flow holes through the support; hole configuration is not yet finalized. The entire height of the reactor canister is not shown, and not all plates are shown. A lateral cross section would show the reflector box as a square surrounding the fuel and the reactor canister as a circle (see Figure 4-2).

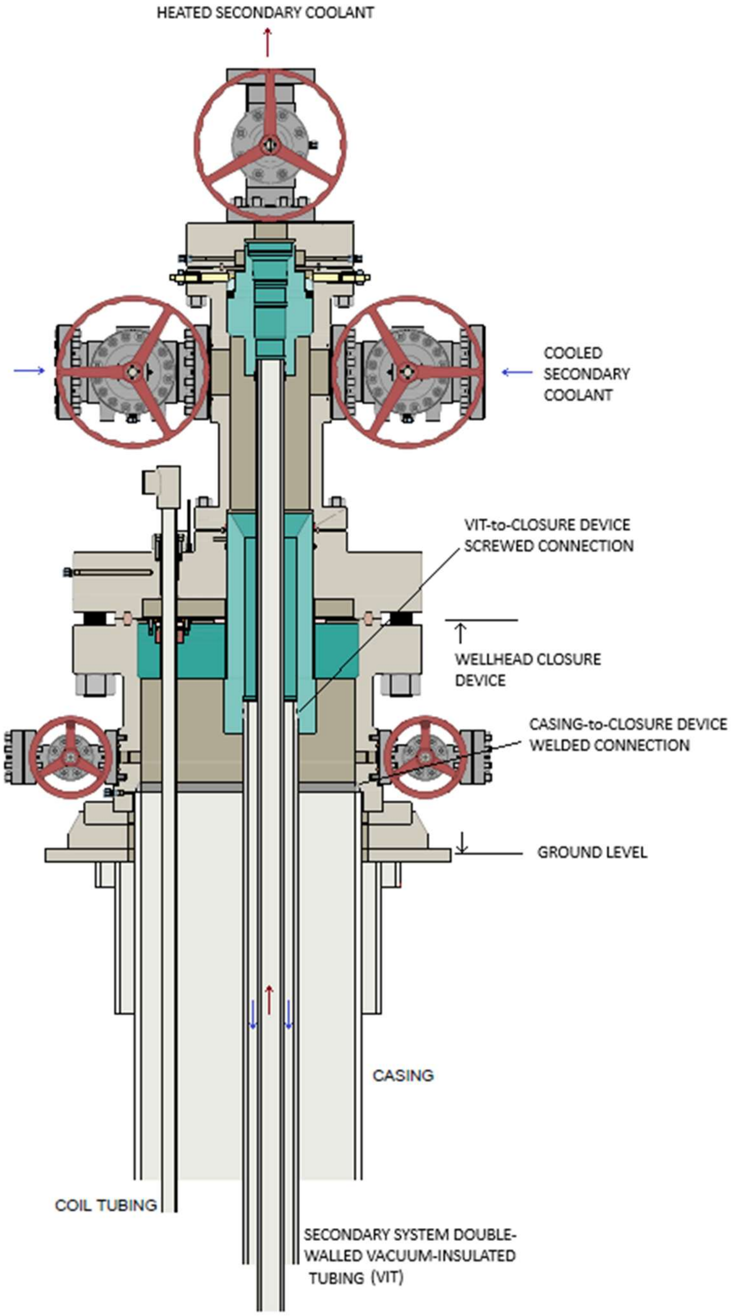

Figure 4-5: Conceptual Borehole Closure Device

Figure 4-5 shows a conceptual borehole closure device (i.e., wellhead) design, along with the connection “tree” on top of the device. The device is welded to the top edge of the borehole casing, and the closure device structurally supports the reactor, reactor canister and internals, PHX, and underground piping via a threaded connection. This threaded connection type is a well-proven, conventional method often used in deep borehole and well drilling operations.

5 Safety Analysis

The safety analysis uses a structured, risk-informed, and performance-based methodology. The approach evaluates plant response to a range of operational and accident conditions.

At the current stage of design, SSC classification is preliminary and subject to refinement as the safety analysis matures and additional design detail is developed.

5.1 Fundamental Safety Functions

The design provides reasonable assurance of adequate protection by ensuring the following fundamental safety functions:

- Radioactive material confinement
- Nuclear reactivity control
- Fission and decay heat removal
- Preservation of adequate radiation shielding

The GDC framework in 10 CFR 50 Appendix A help establish PDCs, informed by 10 CFR 50 (Ref. 8.2.1) Section 34(a)(3) and 10 CFR 52 (Ref. 8.2.2) Section 47(a)(3). For the Gravity Reactor, fundamental safety functions and applicable PDC are fulfilled by a combination of inherent and passive design features. Additional SSCs have been included in the Gravity Reactor design to add layers of protection for the public, workers, and the environment (i.e., DiD). The PDC are considered for SSCs that serve fundamental safety functions and help provide reasonable assurance that the Gravity Reactor is operated without undue risk to the health and safety of the public and workers.

Table 5-1 identifies GDC categories that correspond to fundamental safety functions and the notional allotment of SSCs that fulfill those functions.

Table 5-1: Fundamental Safety Functions Correlation to SSC and GDCs

Fundamental Safety Function	GDC Category	Notional SSC	Inherently Passive Design Characteristics
Radioactive material confinement	II. Protection by Multiple Fission Product Barriers V. Reactor Containment	Fuel matrix Fuel cladding Primary system boundary	Geological isolation Hydrostatic water column

Fundamental Safety Function	GDC Category	Notional SSC	Inherently Passive Design Characteristics
Nuclear reactivity control	III. Protection and Reactivity Control Systems	Soluble boron injection system(s) Fuel poisons Neutron monitoring	Negative reactivity feedback Hydrostatic water column (if combined with soluble neutron absorber)
Fission and decay heat removal	IV. Fluid Systems	Secondary coolant system Tertiary coolant system	Geological isolation Hydrostatic water column
Preservation of adequate radiation shielding	II. Protection by Multiple Fission Product Barriers VI. Fuel and Radioactivity Control	Borehole structure	Geological isolation Hydrostatic water column

5.2 Safety Analysis

The safety analysis evaluates potential transients and abnormal events, including postulated disturbances in process variables and postulated equipment failures or malfunctions. It provides the basis for SSC design specifications, limiting conditions for operation, and limiting system settings.

The Gravity Reactor is a PWR design that operates at typical temperatures and pressures, uses only a fraction of the conventional fuel loading, and is geologically isolated deep underground. The hazards associated with its operation are known, and SSC that fulfill fundamental safety functions leverage the GDCs and use established designs.

Over the last 70 years, industry and regulators have identified and evaluated a broad spectrum of potential transients and accidents applicable to light water reactors in general and PWRs specifically. Deep Fission's safety analysis leverages this body of work and applies methods endorsed by the NRC.

For transients and accidents unique to the Gravity Reactor design, the project team's evaluation process identifies initiating events for design basis events (DBEs).

Deep Fission uses a systematic and reproducible framework for selecting DBAs, classifying the safety significance of SSC, and determining the adequacy of the DiD strategy. The safety analysis implements steps informed 10 CFR 50 (Ref. 8.2.1) and 10 CFR 52 (Ref. 8.2.2). See Figure 5-1.

Table 5-2 outlines the Gravity Reactor safety analysis.

Table 5-2: Gravity Reactor Safety Analysis Description

Step Number	Step Name	Description
1	Design Development and Performance-Based Entry Screening	Design development and analysis include definition of the elements of the safety design approach, the design features needed to meet top-level design requirements for energy production and investment protection, and analyses to develop sufficient understanding to perform the deterministic safety analyses. Perform plant design development process in initial, preliminary, and final design phases and iterate within those phases. Identify the maximum credible accident, deterministic consequence acceptance criteria, and measurable performance criteria by which to assess the effectiveness of design features. Establish what SSCs and design features will be used for maximum credible accident prevention or mitigation to demonstrate and ensure safety outcome objectives of regulatory requirements are met for the plant.
2	PWR Transient/Accident Initiating Event Screen	Review and screen historically analyzed PWR transients and accidents (i.e., DBEs) for applicability to the Gravity Reactor and identify associated initiating events.

Step Number	Step Name	Description
3	New Hazard Review	Examine the potential for unbounded transients and accidents that have not been previously evaluated for PWRs and identify them as DBEs. Evaluate the unique hazards associated with first-of-a-kind design features, external hazards unique to the geologically isolated configuration, support system interactions, abnormal configurations, and failure modes created by siting the reactor in a borehole and within a hydrostatic water column. Use structured deterministic tools for this evaluation, such as What-If Analysis, hazard and operability study and failure modes and effects analysis. If necessary to further refine the evaluation, consider performance-based analytical methods such as those documented in DG-1414, “Alternative Evaluation for Risk Insights (AERI) Methodology” (Ref. 8.3.7).
4	Initiating Event Categorization	Categorize initiating events for applicable DBEs into anticipated operational occurrences within PWR-specific categories.
5	DBE Categorization	Categorize the applicable anticipated operational occurrences and postulated accidents within families.
6	Deterministic Analysis	Perform deterministic safety analyses on the postulated accidents to determine which accident scenarios require controls to meet the dose consequence acceptance criteria for the accident analysis, as informed by 10 CFR 50 (Ref. 8.2.1) Sections 67(b)(2)(iii) and 34(a)(1)(ii)(D).
7	Safety-Related SSC Identification	Identify safety-related SSC based on the required safety functions necessary for control of postulated accident dose consequences. As these safety-related SSC are important to safety, PDC or other limits need to be applied to their design.
8	DBA Designation	Designate DBAs as those which require safety-related SSC control(s) to meet the applicable dose acceptance criteria.

Step Number	Step Name	Description
9	Technical Specification Derivation	Derive technical specifications to protect DBA assumptions and credited safety-related controls.
10	Safety Analysis Completion Check	Determine if the safety analysis is complete.
11	Return to Design Development	If the safety analysis is not complete, return to design development.
12	Safety Analysis Results Reporting	Document safety analysis results in a Safety Analysis Report for regulatory evaluation and approval.

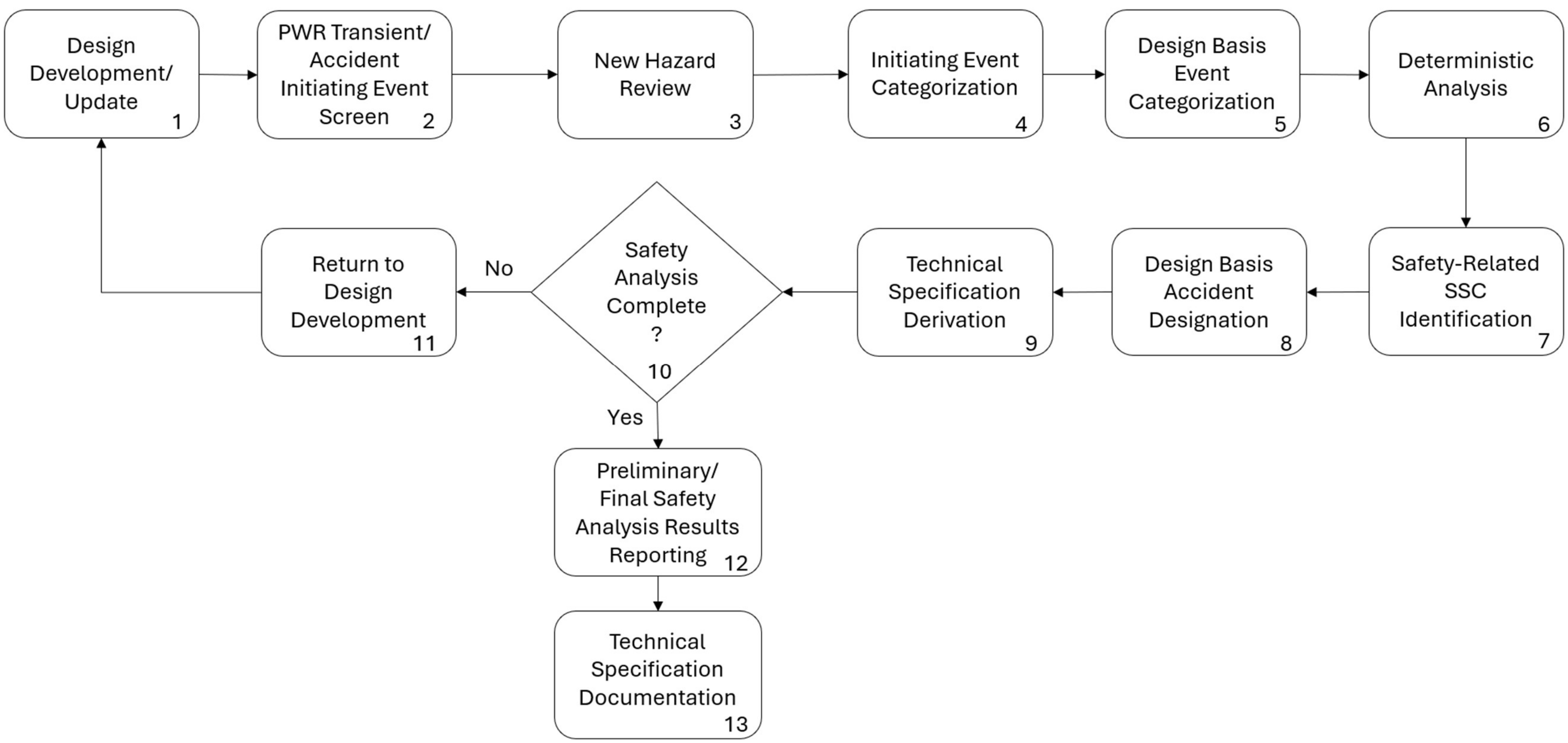

Figure 5-1: Safety Analysis Cycle

Figure 5-1 shows Deep Fission’s safety analysis cycle.

5.3 Safety-Related SSC Identification and Classification

When selecting controls determined to address a fundamental safety function, the Gravity Reactor safety analysis process implements a well-established and widely used hierarchy of controls. Specifically:

- minimization of hazardous material;
- SSCs preferred over administrative controls;
- passive SSCs are preferred over active SSCs;
- preventive controls are preferred over mitigative controls;
- controls closest to the hazard are preferred, because they may provide protection to the largest population of potential receptors, including workers and the public; and
- controls that are effective for multiple hazards are preferred, because they can be resource effective.

Although no deviations are anticipated, any exception taken to this hierarchy will be supported by a technical basis.

For the Gravity Reactor, all SSCs relied upon to prevent a design basis accident or mitigate its dose consequences such that they do not exceed dose acceptance criteria, are classified as “safety-related.” SSCs that are not safety-related but still perform fundamental safety functions and help to provide reasonable assurance that the reactor can be operated without undue risk to the health and safety of workers and the public, are classified as “important to safety.” All safety-related SSCs are also important to safety.

Taking into account the long operating history of PWR reactor designs, the extensive performance data available for SSCs used to control PWR hazards, and key Gravity Reactor design features, the safety analysis process risk-informs the safety-related SSC classification. (Ref. 8.3.6).

Final SSC classification reflects:

- Functional safety requirements
- Event sequence evaluation
- DiD considerations
- Reliability targets and performance objectives

5.4 Defense-in-Depth (DiD)

The design applies DiD through multiple layers of protection, including prevention, mitigation, and containment strategies.

Although the concept of DiD is often discussed in the context of nuclear safety, it does not have a consistent definition. NRC provides a study of the concept in NUREG/KM-0009, "Historical Review and Observations of Defense-in-Depth," (Ref. 8.3.4), which concludes that, despite differing definitions, experts generally agree that DiD is necessary to compensate for uncertainties in reactor design and operation, the performance of SSC and operator actions, natural phenomena, accident progression, and other parameters and events.

DiD aims to address these uncertainties and ensure that operation keeps risk to public health and safety acceptably low. The design employs the following layers of protection.

5.4.1 Layer 1 – Prevention of Abnormal Operation and Failures

Accident prevention is the first priority. The Gravity Reactor achieves this through passively safe design, siting, construction, operations, and maintenance practices, and by using high-quality materials. These provisions prevent deviations of the reactor state from well-understood operating conditions. Such measures are generally more effective and predictable than those aimed at mitigating departures.

The Gravity Reactor uses commercially available LEU PWR fuel with extensive operational history and predictable transient behavior. The core design simplifies and facilitates reactivity control.

5.4.2 Layer 2 – Control of Abnormal Operation and Detection of Failures

The Gravity Reactor controls abnormal operation and detects failures through normal control and indication systems, along with additional surveillance features. SSC and administrative controls provide redundant and diverse means of maintaining control of the reactor and its operating state. Multiple, independent detection methods monitor vital reactor processes and parameters, such as core neutron flux, temperature, and coolant flow. Implementation of PDCs ensures that SSC important to safety directly protect the reactor's fundamental safety functions.

5.4.3 Layer 3 – Control of Accidents Within the Design Basis

A central element of DiD is minimizing the radioactive source term and using multiple successive physical barriers to protect against the accidental release and transport of radioactivity and hazardous materials, while relying on diverse and independent means to perform safety functions.

The Gravity Reactor is designed to reduce the controls necessary to mitigate post-design basis accident dose consequences to acceptable levels. Primary control of postulated accident consequences is accomplished by inherent and passive design features (e.g., geologic isolation within a borehole and hydrostatic water column above the reactor), which are both preventive and mitigative. In addition, passive and active engineered safety features (e.g., cladded solid oxide fuel and reactivity control systems), which are also capable of controlling transients, have been incorporated into the design.

The Gravity Reactor core is geologically isolated nominally one mile underground and immersed within a hydrostatic column of water at that depth. This passive barrier is redundant to the fuel matrix, fuel cladding, and canister that contains the fuel assemblies. Together, the barriers are redundant and diverse and will work in succession to mitigate the transport of radionuclides. In addition, engineered systems for cooling and reactivity control also contribute to this layer of protection by preventing and mitigating potential releases.

5.4.4 Layer 4 – Control of Severe Facility Conditions

This layer provides protection against severe accidents by controlling extreme plant conditions and mitigating consequences beyond the design basis. Passive design features as described in the previous layer prevent initiating events from progressing beyond the design basis and effectively mitigate radionuclide releases even under more severe postulated conditions. Emergency preparedness procedures add further protection and mitigation capability.

5.4.5 Layer 5 – Mitigation of Radiological Consequences Beyond the Design Basis

Anticipatory emergency planning and response procedures provide additional protection. Emergency management planning establishes mechanisms for protecting the public and workers should other barriers fail.

6 Structural Integrity, Materials, Inspection, and Codes

The design selects materials and codes based on functional requirements, environmental conditions, and performance expectations. Material selection, inspection strategies, and code applicability continue to be refined as design detail increases.

The Gravity Reactor design follows proven nuclear, borehole, and pressure vessel industry codes, standards, and inspection methods. An element of the design that is new to the nuclear industry is the relative inaccessibility of downhole components. However, Deep Fission's design mitigates the need for traditional inspection methods. Design objectives are (1) to have no moving parts in the borehole and (2) to ensure inspection and maintenance intervals for submerged primary and secondary SSC that require retrieval of downhole components are longer than the life of the reactor.

6.1 Structural Integrity and Hazards

Structural integrity is treated as a system-level concern centered on interfaces. The integrity of safety-relevant boundaries and interfaces is maintained across the full life cycle while accounting for credible loads from normal operation and natural phenomena hazards.

Seismic and other natural phenomena hazard considerations are addressed through site characterization and conventional structural design practices (Section 3.3).

6.2 Material Selection and Corrosion Considerations

The Gravity Reactor's materials and corrosion strategy is shaped by two close-coupled design aspects: the pressurized light water primary coolant inside the primary boundary, and the external borehole environment. Unlike a conventional above-ground PWRs where many components are routinely accessible, the downhole configuration places a premium on proven materials, conservative corrosion margins, and condition monitoring because maintenance access is intentionally limited during normal operation. Deep Fission's approach:

- Applies established PWR materials and coolant chemistry principles to the primary system.
- Applies established deep borehole and well materials where applicable in the borehole environment.
- Treats borehole water as a controlled "engineered environment" to account for corrosion, scaling, and chemistry drift.

Material selection is driven by:

- Compatibility with PWR coolant practices

  The primary system incorporates standard PWR chemistry and corrosion control principles. Material choices favor alloys with well-understood behavior in pressurized, high temperature water, including resistance to general corrosion and stress corrosion mechanisms under expected chemistry conditions.

- Pressurized downhole environment

  The hydrostatic head at depth creates a stable, external pressure roughly equal to primary coolant pressures. Materials must maintain mechanical properties and leak-tight performance under high pressure equilibrium and thermal cycling, while also tolerating transient conditions.

- Borehole environment control and monitoring

  The borehole water and borehole closure device systems facilitate monitoring and management of chemistry, enabling corrosion control for casing and immersed components such as control of dissolved oxygen, pH, scaling tendencies, and contaminants that could accelerate corrosion.

- Limited accessibility during operation

  Because routine hands-on inspection or repair of downhole hardware is infrequent, materials and components are selected to reduce reliance on in situ maintenance. This emphasizes robust fabrication methods, conservative design margins, and degradation mechanisms that can be monitored indirectly (e.g., chemistry, temperature, leakage indicators, and other system parameters).

- Manufacturability, qualification, and code alignment

  Preference is given to widely used nuclear- and industry-qualified materials and joining methods with mature supply chains, well-characterized properties, and clear Code of Record and quality assurance expectations.

The primary system chemistry program and the borehole water conditioning and monitoring program are implemented to preserve material integrity over time. The borehole and surface infrastructure support multiple reactor operating intervals. Long-life elements (e.g., casing, borehole water management, and surface handling interfaces) are designed and managed for longevity, while the replaceable reactor systems are designed for reliable service over their planned operating interval.

6.3 Inspection and Condition Monitoring

Direct physical access to the subsurface systems is infrequent during normal operations. This is not unique; many safety-significant components in conventional reactors are effectively inaccessible during power operations due to radiation, temperature, and containment boundaries.

The Gravity Reactor’s architecture makes access pathways longer. Accordingly, design aspects must, of necessity, be more deliberate; inspection and integrity assurance are achieved primarily through robust design choices and monitoring strategies. The use of active components in the borehole is reduced or eliminated, resulting in a reduction of failure modes.

Planned access events allow for direct inspection. Where direct inspection is impractical, the design favors measurable proxies and redundant indications that can confirm system health from the surface.

The Gravity Reactor’s accessibility posture reflects a deliberate tradeoff: placing the nuclear heat source deep underground reduces exposure to many surface hazards and limits access to special nuclear material, but hands-on access is limited. The design addresses this tradeoff by ensuring the subsurface portion does not require routine intervention to remain safe and reliable.

6.4 Quality Assurance and Verification

The Gravity Reactor applies a graded quality assurance approach that scales requirements, documentation rigor, and oversight with the credited role of an SSC in preserving safety functions. Safety-related items receive the highest rigor in procurement controls, traceability, fabrication and inspection hold points, and configuration management.

Verification is an evidence-based process that combines analysis, test, inspection, and monitoring to confirm requirements are met. Verification expectations are established early, tied to specific functions and assumptions, and refined as design maturity increases. Each safety function has a clear verification path and documented basis.

6.5 Codes, Standards, and Code of Record

The Code of Record provides clear requirements for design, fabrication, inspection, and testing of safety boundaries and systems. Code selection is guided by safety function, operating conditions, accessibility and inspection constraints, and the quality and integrity requirements. When a configuration requires interpretation or adaptation of a code or standard, the design preserves the safety objectives and documents the basis for equivalencies in a controlled, traceable manner.

6.6 Requirements Flowdown, Systems Engineering Traceability, and Verification Planning

Requirements flowdown begins with plant-level objectives and criteria, including fundamental safety functions and PDCs, and flows down into subsystem requirements and interface requirements.

Using a graded approach, traceability is maintained from requirements to design decisions to verification evidence. For functions and key assumptions credited for safety during postulated accidents, the project establishes a verification plan describing what is demonstrated by analysis, what must be proven by test, and what is confirmed through inspection and operational monitoring.

7 Summary

The Gravity Reactor design has progressed from an initial conceptual state to a more mature and integrated configuration. The current design reflects improved definition of system architecture, safety approach, and engineering considerations.

While the design has matured, further development is ongoing. Key areas, including detailed component design and final SSC classification, continue to evolve through analysis, testing, and engineering refinement.

This document provides a technically grounded description of the current design state to support internal alignment, regulatory engagement, and stakeholder understanding.

8 References

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8.1.2 NRC memorandum, “U.S. Nuclear Regulatory Commission Summary of the July 10, 2024, Public Meeting to Discuss the Conceptual Design of Deep Fission’s Deep Borehole Pressurized Water Reactor,” ADAMS accession number ML24222A441. Document date August 21, 2024.

8.1.3 Executive Order 14300, “Ordering the Reform of the Nuclear Regulatory Commission,” 90 FR 22587. Signed May 23, 2025.

8.2 Regulations

8.2.1 10 CFR 50, NRC “Domestic Licensing of Production and Utilization Facilities.” Accessed January 2026.

8.2.2 10 CFR 52, NRC “Licenses, Certifications, and Approvals for Nuclear Power Plants.” Accessed January 2026.

8.2.3 10 CFR 100, NRC “Reactor Site Criteria.” Accessed January 2026.

8.3 Guidance

8.3.1 IEEE-379-2014, “IEEE Standard for Application of the Single-Failure Criterion to Nuclear Power Generating Station Safety Systems,” Institute of Electrical and Electronics Engineers (IEEE) Power and Energy Society, May 2014.

8.3.2 NEI Technical Report 25-08, “Graded Approach to Seismic Hazard Analysis and Corresponding Site Investigations for Licensing Nuclear Power Plants,” Revision 0, December 2025. Copy accessible under ADAMS accession number ML25335A221.

8.3.3 NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: Light Water Reactor Edition,” Section 4.2, “Fuel System Design,” Nuclear Regulatory Commission, Revision 3, March 2007.

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